Unit #8
Balancing Chemical Equations, Types of Reactions
Instructor's notes

Chemical Equations

Intro: **What is a chemical equation?** *Answers will vary.*

1) **Chemical Equation -** an expression representing a chemical reaction.

   a) Format: Reactant(s) →→→→ Product(s)
      i) The arrow is read as "yields".
   b) **Reactant(s)-** the starting substance(s) in a reaction.
   c) **Product(s)-** the substance(s) formed by the reaction. (ending substance).

Can anyone tell me the chemical equation for respiration (using words)? Symbols? *Appropriate clues would include: …what do we use for energy? …what other substance must we also take in? …what substances do we produce?*

The reaction is:
Glucose + Oxygen →→→→ Carbon dioxide + Water
$C_6H_{12}O_6$ + $6O_2$ →→→→ $6CO_2$ + $6H_2O$

We will now discuss the commonly used symbols ion a chemical reaction.

2) Symbols used in chemical equations.
   a) **Element symbol**: **What does the element symbol represent?**
      Answer: 1 atom of one element.
   b) **Subscript**: indicates the number of atoms in a molecule. **How many atoms of each element are in a glucose molecule?**
      Answer: C = 6
      H = 12
      O = 6
      i) **NEVER CHANGE THE SUBSCRIPT OF A CORRECTLY WRITTEN FORMULA !**

   Reason: the number of atoms in a molecule is an experimental fact.

c) **Coefficient**: the number to the left of a formula, assumed to be one "1" if not written. **Can anyone tell me what things can be determined by the "coefficient"?** Clue: think about the "Limiting Reagent" lab you recently completed. *Answer: the mole ratio, also the "molecular ratio".*

In the above equation, how many molecules of glucose are required? *Answer: One.* **How many moles of glucose are required?** *Answer: One.* **How many molecules of water are produced?** *Answer: Six.* **How many atoms of hydrogen are produced?** *Answer: Twelve.*

d) $\longrightarrow$: yields, or produces (Reactant(s) →→→ Product(s))

e) + : plus, or combines with.

f) $\rightleftharpoons$: the reaction is reversible. (Can go either way.)

g) $\rightleftharpoons$ (longer forward arrow) : the reaction is reversible, but, favors the products.

h) $\rightleftharpoons$ (longer reverse arrow) : the reaction is reversible, but, favors the reactants.

i) $\xrightarrow{\Delta}$: in the presence of heat. (The reactants must be heated.)

j) $\xrightarrow{\text{catalyst}}$: in the presence of a catalyst.

i) **<u>Catalyst -</u>** 1. a substance that speeds up a chemical reaction without being used up.
2. Lowers the activation energy.

3. Enzymes are biological catalysts.

k) N.R. : no reaction.

l) (s) or ↓ : solid or a precipitate.

i) **Precipitate -** 1. (noun) a substance, usually a solid, which separates from a solution as a result of some physical or chemical change.

2. (verb) to make such a substance as previously described.

m) (l) : liquid

n) (g) or ↑ : gas

o) (aq) : aqueous, the substance is dissolved in water.

Balancing Chemical Equations

In all balanced equations:

# of atoms of each element on the left of the "yields" arrow
must equal
# of atoms of each element on the right of the "yields" arrow

Many equations can be balanced by trial and error… However, the following five rules will make balancing quicker.

3) **1.** Write the correct formulas:

a) For all reactants to the left of the arrow.

b) For all products to the right of the arrow.

c) If more than one reactant or product, separate them with a "plus" sign.

4) **2.** Once the correct formula is written: **NEVER** change the subscript(s).

5) **3.** Set up a chart:

a) with all atom types down the left side

b) 2 columns:

i) one labeled left

ii) the other labeled right

6) **4.** Start with any element that appears only once on both sides of the equation.

7) **5.** Balance the elements one at a time by adding coefficients in front of the formulas.

   a) Remember: no coefficient = 1.

   b) Multiply coefficients by the subscript to determine the number of atoms.

   c) Adjust coefficients as necessary.

What thing can we determine from a balanced equation?

Answer: 1. Proportions of reactants & products (Remember: the coefficient shows mole ratio.

2. # of atoms / molecules / formula units / moles

3. From the mole ratio… we can use DIMO to calculate grams.

8) Example: Hydrogen and Iodine react to form Hydrogen iodide.

   a) $H_2 + I_2 \rightarrow\rightarrow\rightarrow 2HI$

9) Example: Hydrogen bromide and Oxygen react to form water and Bromine.

   a) $HBr + O_2 \rightarrow\rightarrow\rightarrow H_2O + Br_2$

   b) $2HBr + O_2 \rightarrow\rightarrow\rightarrow H_2O + Br_2$

   c) $2HBr + O_2 \rightarrow\rightarrow\rightarrow 2H_2O + Br_2$

   d) $4HBr + O_2 \rightarrow\rightarrow\rightarrow 2H_2O + Br_2$

   e) $4HBr + O_2 \rightarrow\rightarrow\rightarrow 2H_2O + 2Br_2$

10) Example: Carbon dioxide and water in the presence of sunlight and chlorophyll react to produce glucose ($C_6H_{12}O_6$) and oxygen.

   a) $CO_2 + H_2O \rightarrow\rightarrow\rightarrow C_6H_{12}O_6 + O_2$

   b) $6CO_2 + H_2O \rightarrow\rightarrow\rightarrow C_6H_{12}O_6 + O_2$

   c) $6CO_2 + 6H_2O \rightarrow\rightarrow\rightarrow C_6H_{12}O_6 + O_2$

   d) $6CO_2 + 6H_2O \rightarrow\rightarrow\rightarrow C_6H_{12}O_6 + 6O_2$

11) Example: Copper and concentrated Nitric acid react to form Copper (II) nitrate, water, and Nitrogen dioxide.

a) $Cu + HNO_3 \rightarrow\rightarrow\rightarrow Cu(NO_3)_2 + H_2O + NO_2$

	Left	Right
Cu	1	1
H	1, 4	2, 4
N	1, 4	3, 4
O	3, 12	9, 10, 12

b) $Cu + 4HNO_3 \rightarrow\rightarrow\rightarrow Cu(NO_3)_2 + H_2O + NO_2$

c) $Cu + 4HNO_3 \rightarrow\rightarrow\rightarrow Cu(NO_3)_2 + 2H_2O + NO_2$

d) $Cu + 4HNO_3 \rightarrow\rightarrow\rightarrow Cu(NO_3)_2 + 2H_2O + 2NO_2$

12) Example: Sodium hydroxide and Sulfuric acid react to yield Sodium sulfate and water.

a) $NaOH + H_2SO_4 \rightarrow\rightarrow\rightarrow Na_2SO_4 + H_2O$

b) $2NaOH + H_2SO_4 \rightarrow\rightarrow\rightarrow Na_2SO_4 + H_2O$

c) $2NaOH + H_2SO_4 \rightarrow\rightarrow\rightarrow Na_2SO_4 + 2H_2O$

	Left	Right
Na	1, 2	2
O	5, 6	5, 6
H	3, 4	2, 4
S	1	1

13) Example: Barium hydroxide and Nitric acid react to form Barium nitrate and water.

a) $Ba(OH)_2 + HNO_3 \rightarrow\rightarrow\rightarrow Ba(NO_3)_2 + H_2O$

b) $Ba(OH)_2 + 2HNO_3 \rightarrow\rightarrow\rightarrow Ba(NO_3)_2 + H_2O$

c) $Ba(OH)_2 + 2HNO_3 \rightarrow\rightarrow\rightarrow Ba(NO_3)_2 + 2H_2O$

	Left	Right
Ba	1	1
O	5, 8	7, 8
H	3, 4	2, 4
N	1, 2	2

14) Example: Hydrochloric acid reacts with Aluminum to produce Hydrogen and Aluminum chloride.

a) $HCl + Al \rightarrow\rightarrow\rightarrow H_2 + AlCl_3$

b) $3HCl + Al \rightarrow\rightarrow\rightarrow H_2 + AlCl_3$

c) $3HCl + Al \rightarrow\rightarrow\rightarrow 3/2\ H_2 + AlCl_3$
(multiply everything through by 2)

d) $6HCl + 2Al \rightarrow\rightarrow\rightarrow 3H_2 + 2AlCl_3$

Types of Chemical Reactions

15) **Endothermic-** absorbs energy (heat) from its surroundings.

a) $Ba(OH)_2 \cdot 8H_2O + 2NH_4NO_3 \rightarrow\rightarrow\rightarrow Ba(NO_3)_2 + 2NH_3 + 10H_2O$

16) **Exothermic-** releases energy to its surroundings.

a) $Mg + 2HCl \rightarrow\rightarrow\rightarrow H_2 + MgCl_2$

17) **Combustion-** an element or compound reacts with oxygen, often producing energy (heat & light).

a) Combustion of an element:

i) *General formula:* $A + O_2 \rightarrow\rightarrow\rightarrow AO_2$

ii) $S + O2 \rightarrow\rightarrow\rightarrow$ SO2 (+ energy (fire))

iii) $2Mg + O_2 \rightarrow\rightarrow\rightarrow 2MgO$ (+ energy (fire))

b) Combustion of a hydrocarbon:

i) **Hydrocarbon-** an organic compound that contains only Carbon and Hydrogen.

ii) *General formula:* $C_xH_y + O_2 \rightarrow\rightarrow\rightarrow CO_2 + H_2O$

iii) $CH_4 + 2O_2 \rightarrow\rightarrow\rightarrow CO_2 + 2H_2O$

18) **Synthesis-** also known as "combination" reactions; two or more substances react to form a single substance.

a) *General formula:* $A + B \rightarrow\rightarrow\rightarrow AB$

b) $2H_2 + O_2 \rightarrow\rightarrow\rightarrow 2H_2O$

19) **Decomposition-** a single compound is broken down into two or more simpler substances.

a) *General formula:* $AB \rightarrow\rightarrow\rightarrow A + B$

b) $H_2CO_3 \rightarrow\rightarrow\rightarrow H_2O + CO_2$

c) $2H_2O \xrightarrow{\text{Electricity}} 2H_2 + O_2$ (this process is called electrolysis, meaning: splitting with electricity)

20) **Single Replacement-** atoms of a more reactive element, replace those of a less reactive element.

These types of reactions depend on the "Activity Series".

a) **Activity series-** a listing of metals in decreasing activity. (Just as in "electrochemistry", any metal above any other metal(s), can replace those below it.

b) *General formula:* $A + BC \rightarrow\rightarrow\rightarrow B + AC$
(A: Solid; BC: Ionic species; B: solid; AC: Ionic species)

(where "A" is more reactive than "B").

What will the products be of the following reactions?

i) $Mg + Zn(NO_3)_2 \rightarrow\rightarrow\rightarrow$ *$Zn + Mg(NO_3)_2$*

ii) $Mg + 2AgNO_3 \rightarrow\rightarrow\rightarrow$ *$2Ag + Mg(NO_3)_2$*

iii) $Mg + LiNO_3 \rightarrow\rightarrow\rightarrow$ *N.R.*

21) **Double Replacement-** exchange of cations between two compounds.

a) *General formula:* $AB + XY \rightarrow\rightarrow\rightarrow XB + AY$

*(will **only** occur if: one of the products is either a solid, gas, or a salt with water)*

b) Example with a ppt. (solid) produced.

i) $Pb(NO_3)_2 + 2KI \rightarrow\rightarrow\rightarrow PbI2 + 2KNO_3$

c) Example with a gaseous product.

i) $H(C_2H_3O_2) + NaHCO_3 \rightarrow\rightarrow\rightarrow Na(C_2H_3O_2) + H_2CO_3$

(1) Note that the H_2CO_3 rapidly undergoes simultaneous reaction:

$$H_2CO_3 \rightarrow\rightarrow\rightarrow H_2O + CO_2$$

What type of reaction is this? *Answer: Decomposition*

d) Examples with a salt and water being produced.

i) $HCl + NaOH \rightarrow\rightarrow\rightarrow NaCl + H_2O$

The following reaction is what occurs when someone takes a small dose of "Milk of Magnesia" for heart burn (large doses act as a laxative:

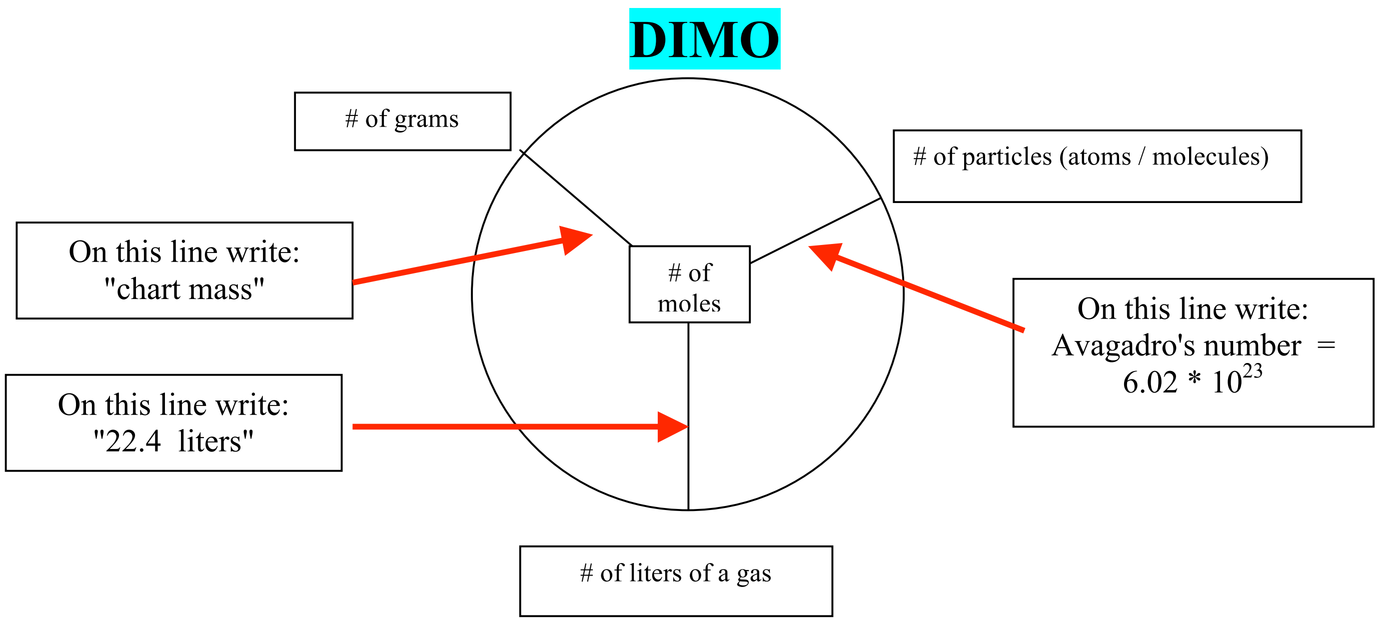
ii) $2HCl + MgCO_3 \rightarrow\rightarrow\rightarrow MgCl_2 + H_2CO_3$ **(which rapidly decomposes into what?** *Answer: $H_2O + CO_2$*)

Calculations from Balanced Reactions

22) DIMO **What does this represent?** *Answer: "Divide In, Multiply Out".*

See "Unit 5" if you need to refresher on this concept.

DIMO - an acronym that means: Divide In Multiply Out.



Consider the following examples:

In each example it is recommended that you:

First, balance the equation.

Then, calculate the "theoretical" mole ratio.

Using the theoretical mole ratio, determine the actual mole ratio(s).

Finally, use "DIMO" to determine the number of grams/liters/ particles… as requested in the question.

23) 468 grams of Propane (Tri-carbon octa-hydride)will combust. What will be the mass of the reactants and products.

a) **What is the balanced equation?**
Answer: $C_3H_8 + O_2 \rightarrow\rightarrow\rightarrow CO_2 + H_2O$

$C_3H_8 + 5O_2 \rightarrow\rightarrow\rightarrow 3CO_2 + 4H_2O$

b) **What is the theoretical ratio of moles required or produced for/by the reaction?**
Answer: 1 mole C : 5 moles O_2 : 3 moles CO_2 : 4 moles H_2O

c) In this example, you must now use "DIMO" to determine the actual moles of Propane reacted. **How many moles of Propane are reacted?** *Answer: 44.0962g / mole of propane, using "DIMO" we divide 468g / 44.0962g/mole = 10.6 moles.*

d) **What is the actual ratio of moles for this reaction?**
Answer: 10.6 mole C : 53 mole O_2 : 31.8 mole CO_2 : 42.4 mole H_2O

e) **How many grams of:**

i) **Oxygen are required?**
Answer: 53 mole * 32g/mole = 1700g (1696)g of O_2

ii) **Carbon dioxide are produced?**
Answer: 31.8 mole * 44.0098g/mole = 1400g of CO_2

iii) **Water are produced?**
*Answer: 42.4 mole * 18.0152g/mole = 764g of water*

A chart like the one that follows is often very helpful.

Symbols	C_3H_8	+	O_2	→→→	CO_2	+	H_2O
Balanced equation	C_3H_8	+	$5O_2$	→→→	$3CO_2$	+	$4H_2O$
Theoretical moles	1		5		3		4
Actual moles	10.6		53		31.8		42.4
grams	468		1700		1400		764

24) At high temperatures (like those found during a fire), Ammonium nitrate decomposes violently forming: Nitrogen, Oxygen, and water vapor. Assuming all 500g in the "stock container" were compromised during such an accident, what mass of reactants would be produced.

a) **What is the balanced equation?**

Answer: $NH_4NO_3 \rightarrow\rightarrow\rightarrow N_2 + O_2 + H_2O$

$2NH_4NO_3 \rightarrow\rightarrow\rightarrow 2N_2 + O_2 + 4H_2O$

b) **What is the theoretical ratio of moles required or produced for/by the reaction?**

Answer: 2 mole NH_4NO_3 : 2 moles N_2 : 1 moles O_2 : 4 moles H_2O

c) In this example, you must now use "DIMO" to determine the actual moles of Ammonium nitrate reacted. **How many moles of Ammonium nitrate are reacted?** *Answer: 80.0342g / mole of Ammonium nitrate, using "DIMO" we divide 500g / 80.0342g/mole = 6.25 moles.*

d) **What is the actual ratio of moles for this reaction?**

Answer: 6.25 mole NH_4NO_3 : 6.25 mole N_2 : 3.125 mole O_2 : 12.5 mole H_2O

e) **How many grams of:**

i) **Nitrogen are produced?**

Answer: 6.25 mole * 28.0134g/mole = 175.084g of N_2

ii) **Oxygen are produced?**

Answer: 3.125 mole * 32g/mole = 100g of O_2

iii) **Water are produced?**

*Answer: 12.5 mole * 18.0152g/mole = 225.19g of water*

Again, a chart like the one that follows can be very helpful.

Symbols	NH_4NO_3	+	N_2	→→→	O_2	+	H_2O
Balanced equation	$2NH_4NO_3$	+	$2N_2$	→→→	O_2	+	$4H_2O$
Theoretical moles	2		2		1		4
Actual moles	6.25		6.25		3.125		12.5
grams	500		175.084		100		225.19

25) A person exhaled 100 liters (equal to the volume of a 10 cubic meter room) of CO_2 while jogging. Assuming 4% of the exhaled CO_2 was already in the air (it was inhaled):

a) **How much CO_2 did this person actually produce?**

i) *Answer: 100 liters - 4% = 96 liters.*

b) Assuming all of this CO_2 was the result of the body's "combustion" of glucose: **How many grams of glucose were utilized?**

i) *Answer:*

$$C_6H_{12}O_6 + 6O_2 \rightarrow\rightarrow\rightarrow\rightarrow 6CO_2 + 6H_2O$$

Like the previous two examples you now must determine the "mole ratios" involved.

ii) Answer:
96 liters of CO_2 / 22.4 liters/mole = 4.3 (4.2857) mole of CO_2

iii) **What are the actual mole ratios of Glucose to Carbon dioxide?**

Answer: The theoretical ratio is 1: 6, therefore the actual ratio has to be: 0.72 : 4.3

iv) Finally, you must convert the 0.72 moles of glucose into grams.
*Answer: 0.72 mole * 180.1572g/mole = 129.7 grams of glucose*

This is equivalent to 0.286 pounds = 4.58 ounces. (Note: other factors were neglected here, like the "Gas Laws" and any aerobic respiration that might have occurred.)